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The Management of Aerospace Technology in Japan—An Assessment of the Research Infrastructure

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13. ABSTRACT (Maximum 200 words)

Aerospace is one of the few remaining technologies in which the U.S. is demonstrably ahead of its Japanese counterpart. Such leadership role can only be maintained through aggressive and active support for the infrastructure of the research and development efforts in this technology area. The two main infrastructure elements in aerospace research and development are ground-based testing facilities and computational resources. This report presents a survey of the major Japanese civilian and military aeronautical ground testing and computational facilities, including the Japan National Aerospace Laboratory and the Third Research Institute. Also, four of Japan's five major aerospace industries are surveyed. An assessment of the Japanese management approach for aerospace technology is formulated on the basis of the survey.

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PREFACE

The work reported herein was performed jointly by AEDC and the University of Tennessee Space Institute (UTSI). The work performed by UTSI was funded by the U.S. Air Force Office of Scientific Research through a subcontract from Vanderbilt University's United States–Japan Center for Technology Management. The manuscript was submitted for publication on April 16, 1996.

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1.0 INTRODUCTION

This report represents an aerospace scientist's and test engineer's view on the current methodologies adopted in the management of aerospace technology in Japan. The aim of this study is to present an analysis of those elements that comprise all aerospace technology management in Japan-civilian government agencies, military agencies, and industry. An assessment is made of the major Japanese aerospace testing and computational facilities. Such facilities represent the relevant infrastructure for aerospace technology research and development. Typically, the major facilities are provided by the government through its various laboratories. The National Aerospace Laboratory is the only civilian laboratory in Japan that is entirely dedicated to aerospace research, and as such, maintains the best testing and computational facilities. The assessment of the capabilities of these facilities is the primary objective of this report.

Aerospace technology is quite unique among other technologies in that it is highly specialized with limited markets, but is extraordinarily essential to national security. The relevance of aerospace technology for national security in war time has been clearly demonstrated on all battlefields since WW I and recently during the Gulf War. Consequently, the support by the military establishment, especially in financial terms, has been a key driver of all progress in aerospace technology to date. This certainly has been true in the United States for the past 80 years and was particularly true during the Cold War era. Such support of aerospace technology by the military establishment has, in turn, created a serious dependence of the aerospace industry on the national government. With declining military budgets, however, the question to be asked now is whether aerospace technology can continue to advance when it is no longer crucial for national security. In other words, is it possible for aerospace technology to still support a viable profit making industry without governmental interference and without de facto government subsidies.

Up to the present time, the United States has remained the world leader in aerospace technology development. This technological superiority has allowed the U.S. aerospace industry to be positioned as the undisputed leader in the world markets. In fact, the export of aerospace products, both civilian and military, has been responsible for a substantial portion of the credit in the U.S. trade balance. How much longer can the United States maintain its leadership in this industry is a question that can only be answered after careful examination of the aerospace technology development by other viable competitors. China, Germany, Japan, and Russia are the main likely rivals in this technology. This report is concerned with the present day state of aerospace technology in Japan.

The advancement of any technology, including aerospace depends, in an essential way, on the conduct of research and development particular to that technology. Management plays a key role in the development of any technology since it oversees the delicate balance between the research and development aspect and the utilization of that technology by industry. Testing and computational facilities, such as wind tunnels and computers, are the most essential tools for conducting aerospace technology research and development. Aerospace technology is unique among other technology areas in that its progress is dependent in a very strong way on the capabilities of its testing facilities as well as the speed and size of the computational machines used. Also unique in aerospace technology is that both elements, the testing and computational facilities, are essential since both interact and complement each other strongly. No progress can be made with exclusive reliance on one alone (see Ref. 1). In fact, the strength of any nation in aerospace technology development can be readily measured through careful assessment of the capabilities of its ground testing and computational facilities. The management of these facilities, manifested in the efficiency and degree of utilization of the available aerospace testing and computational resources, is key to the development of aerospace technology.

The present report, for the most part, is based on two visits to Japan conducted by the authors for the purpose of understanding Japanese practices in the management of aerospace technology. While in Japan, the authors were able to visit the National Aerospace Laboratory, the Third Research Center, and four of Japan's five major aerospace industries. Despite this broad orientation, this report should not be viewed as the final statement on the Japanese aerospace technological capability. There are many more issues requiring additional insight and consideration.

2.0 BACKGROUND

Japan is considered today one of the major, if not the major, industrial nation in the world. It is miraculous how such a tiny landmass, possessing no substantial natural resources, has developed into the present industrial and economic giant, when only 150 years ago it was an isolated, feudal state. However, before WW II, Japan was substantially developed industrially in most relevant technologies, including aerospace technology. For a comprehensive review of the historical development of aerospace technology in Japan, the reader is referred to the excellent discussion found in Ref. 2.

After its surrender to the Allies, Japan was allowed to develop its economy and political structure following the model of Western democracy. Its industrial development was essential for its economic recovery. This was the case in most key industries except the aerospace industry. The articles of surrender prohibited the conduct of any research and development in aerospace technology. As a consequence, Japanese industry and government depended exclusively on the Allies, and principally the United States, to fulfill its aerospace technology requirements. This break in the development of aerospace sciences is the reason why aerospace technology in Japan today is lagging behind other technologies such as the semiconductor and electronics technologies.

Before WW II, Japan was certainly as advanced as the Allies and Germany in many aspects of aerospace technology. This is evidenced by the fact that in 1942 the Japanese army established an aeroacoustic research base on the grounds of the present National Aerospace Laboratory. Substantial aerospace research was conducted at that base until the end of the war. After the surrender, Gen. Douglas MacArthur instructed that all unused land on the base be returned to its original farmer owners and that most of the test buildings be demolished. Only a few remaining laboratories were converted to civilian use for the conduct of research on ship and locomotive technology. After the war, this base was renamed the Transportation Research Laboratory and was placed under the auspices of the Ministry of Transportation. In 1955–56 the National Aerospace Laboratory was established on the same grounds with many new buildings built by the Science and Technology Agency. Another interesting fact relating to Japan's progress in aerospace technology is that Japan had completed all diagnostic testing of its first domestically manufactured jet engine just before the end of the war.

The aerospace industry in Japan began to revive in 1952 when Japan was contracted to perform repairs on military aircraft belonging to the U.S. forces stationed there. Shortly after that, industry began producing military aircraft under license for the Japanese Defense Agency (JDA). At the present time Japan participates with major international aircraft and jet engine manufacturers as partners, including Boeing, Lockheed, Pratt and Whitney, General Electric, Rolls Royce, and others. In addition, Japan had in the past, and continues to manufacture wholly Japanese aircraft such as the T-1 intermediate trainer, the C-1 transport, the YS-11 turboprop airliner, the MU-12/300 business aircraft, the F-1 support fighter, the T-2 advanced jet trainer, and the T-4 intermediate jet trainer. The V2500 jet engine, considered one of the most advanced jet engines today, is mostly Japanese developed and produced. Similarly, the H-II rocket, which is capable of launching a geostationary satellite of up to two tons, is also an exclusively Japanese effort.

Many similarities and some differences exist between the United States and Japan in the methodologies adopted by government and industry in the development of aerospace technology. The aerospace industry in Japan is similar to United States aerospace industry in that it relies too heavily on governmental support. It is a fact that Japanese aerospace industry depends, at the present time, for up to 80 percent of its business on the defense establishment. Table 1 shows the military contract amounts (in Japanese Yen) for the top 20 companies in Japan. However, unlike the United States, there does not exist in Japan a single aerospace manufacturer that is totally dedicated to that business. Aerospace business in all major aerospace manufacturers in Japan, including the biggest five, comprises only a small portion of their overall business – no more than approximately 20 percent in all cases investigated. On the other hand, aerospace technology in Japan is nurtured by the same three major organizations as in the United States. These are the civilian government, the military establishment, and industry. However, the interaction, exchange of information, and the funding process among the three components are extremely complex and intricate, and differ greatly from those in the United States.

On the civilian government side, four separate ministries and one ministerial level agency are responsible for developing the aerospace technology infrastructure in Japan at varying levels of involvement. These are the Ministry of Education (MOE); the Ministry of International Trade and Industry (MITI); the Ministry of Transport (MOT); the Ministry of Posts and Telecommunications (MOPT); and the Science and Technology Agency (STA), which is under the Prime Minister's office. On the military side, the Japan Defense Agency (JDA) is the main driver for aerospace technology development.

On the industrial side, ten major industries are responsible for almost all of the aerospace business in Japan. These are Fuji Heavy Industries (FHI); Fujitsu Electronics Corp.; Hitachi Corp.; Ishikawajima-Harima Heavy Industries (IHI); Kawasaki Heavy Industries (KHI); Mitsubishi Heavy Industries (MHI); NEC Corp.; Nissan Motor Corp.; ShinMayawa Industries Ltd. (SMIC); and Toshiba Corp. In addition to these ten major industries, there exists a large number of dependent and independent smaller subcontractors.

Most of the aerospace research and development efforts that are supported by the civilian government are conducted at national research laboratories and universities. All research activities undertaken by universities and educational institutions in Japan are directly supported by the Ministry of Education. MOE also supports the Institute of Space and Astronautical Sciences (ISAS), because ISAS initially belonged to Tokyo University, but later became independent. STA supports the National Aerospace Laboratory (NAL), whose charter is somewhat analogous to the National Aeronautics and Space Administration in the United States. STA also directly supports the National Space Development Agency of Japan (NASDA). MOT supports the Electronic Navigation Research Institute as well as the Meteorological Satellite Center. Aerospace research supported by MITI is conducted at the National Research Laboratory of Metrology, the Mechanical Engineering Laboratory, and Osaka National Institute. All of these laboratories are administered for MITI by the Agency of Industrial Science and Technology (AIST). All aerospace research activities supported by the military establishment are conducted at one major laboratory that belongs to JDA. This is the Third Research Center that belongs to JDA's Technical Research and Development Institute. Figure 1 shows a schematic diagram of the governmental agencies, both civilian and military, that are directly involved in aerospace technology research and development.

All industrial aerospace research and development activities are coordinated by the Society of Japan Aircraft Companies (SJAC). SJAC is a non-profit trade association whose members are mainly Japanese enterprises engaged in the manufacture of aircraft, engines, avionics, equipment, space vehicles, and related products in Japan. The objective of the society is to contribute towards upgrading industrial activities, as well as the national welfare, by encouraging the manufacture of aerospace products and expanding the international trade of aerospace and its related products. The membership of SJAC at the present time consists of 177 Japanese firms engaged in manufacturing, repairing, or trading of aircraft, satellite and launch vehicles, and their propulsive and other associated equipment. MITI, actively supports SJAC through the Japan Aircraft

Development Corp. (JADC), and the Japan Aero Engine Corp. (JAEC). Both JADC and JAEC are non-profit, government organizations administered by MITI, which were created solely for the purpose of funding and supporting aerospace research and development programs at SJAC and various industries. Figure 2 shows a schematic diagram of the inter-relationships between government and industry in research and development activities in aeronautics in Japan.

Duplication in aerospace research and development activities and manufacturing is normally discouraged in Japan. Most of the industries involved in aerospace manufacturing, as well as the major national laboratories engaged in aerospace research and development, are encouraged to specialize in one or more components of that technology. These organizations are advised by the various ministries and agencies on which projects or components of projects to pursue. Since conformity is a strong social trait in Japan, industries and national laboratories tend to follow the government recommendations that free them from the burdens of the consequences of failure. Thus, all concerned tend to dedicate their efforts to do best in the tasks they are asked to do (typically their areas of specialization). It is an optimum environment that is poised for great success.

NASDA was established in 1969 as the central organization responsible for implementing space development. NASDA's main mission involves developing satellites and space launch vehicles; launching and tracking of satellites; promotion of space utilization; and devising methods, facilities, and organizations for these purposes and in accordance with the Space Development Program. NASDA has facilities in various parts of Japan for implementing its charter. NASDA has developed, manufactured under contract, and used the N-I, N-II, H-I, and H-II orbital launch vehicles. Seven satellites were launched with the N-I rocket; eight satellites related to meteorology, telecommunications, and broadcasting were launched with the N-II; and nine successful launches were accomplished with the H-I vehicle. The H-II rocket is Japan's latest launch vehicle, is totally Japanese in development and production, and is capable of launching heavy payloads. All satellites and launch vehicles are manufactured by Japan's aerospace industry under contract with NASDA and other organizations.

ISAS is the main institute responsible for developing space and astronautical sciences in Japan, and also conducts space-based scientific research using space vehicles. For this purpose, it develops and operates sounding rockets, satellite launchers, scientific satellites, planetary probes, and scientific balloons. ISAS, in its current status, was founded in 1981 by reorganizing the Institute of Space and Astronautical Science at the University of Tokyo that housed the core of Japanese space research infrastructure from 1961 until then. ISAS is also involved in graduate students' education and training in space science under agreements with a number of universities. A number of the scientific staff at ISAS also carry joint faculty academic appointments at various universities throughout Japan.

NAL, which was formerly called the National Aeronautics Laboratory, was established in 1955 for the purpose of conducting research and development in the aeronautical sciences. In 1963, NAL was charged with the additional task of conducting research in space technology and

was given its present name, the National Aerospace Laboratory. NAL, due to its charter, has strong working relationships with NASDA through the conduct of various experiments essential to space development. NAL will be discussed in great detail in Section 3.0.

On the industrial side, only five of the major companies are involved in the development and manufacturing of aircraft in Japan. The five major prime contractors are FHI, IHI, KHI, MHI, and SMIC. A division of labor similar to that found in government also exists in aerospace industry in Japan. IHI is the major aircraft engine manufacturer in Japan where it manufactures and services all types of engines either under license or wholly Japanese. It is also involved in a number of joint manufacturing agreements with all major aircraft engine manufacturers around the world. IHI produces jet engines under license from General Electric, Pratt and Whitney, Allison, and Rolls Royce. A considerable portion of IHI's business depends on refurbishing aircraft engines for airlines of most producers.

MHI is considered the largest aircraft manufacturer in Japan and is also the leader in this business. At the present time it manufactures the SH-60J AntiSubmarine Warfare helicopter under license agreement with Sikorski Aircraft Corp. It manufactures the UH-60J rescue helicopter also under license from Sikorsky. MHI manufactured the YS-11/11A turboprop airliner, which is a mid-size, wholly Japanese-developed aircraft. MHI was the prime contractor for the all-Japanese T-2 twin engine, two seater supersonic trainers. MHI was responsible for the forward and middle section of the fuselage for that plane, and FHI was responsible for the main wing and tail section. Also, MHI manufactured the F-1 single seat support aircraft that was based on the T-2. MHI produces the F-15J/DJ jet fighter under license from McDonnel Douglas with KHI as a subcontractor.

KHI, the second largest aircraft manufacturer in Japan, is engaged in various aerospace production activities. At the present time, it produces the P-3C Advanced AntiSubmarine Warfare aircraft under license from Lockheed Corp. It also produces the Kawasaki-Hughes 369 twin engine, tandem rotor, civilian multi-purpose helicopter under license from McDonnel Douglas. Another helicopter produced by KHI is the Kawasaki-Boeing CH-47J large capacity transport helicopter under license from Boeing. KHI is the prime contractor for producing the T-4 intermediate jet trainer. In the past KHI produced the CJ military jet transport airplane that was designed and developed in Japan. Also, KHI produced the Kawasaki Boeing KV107 II twin engine tandem rotor helicopter under license from Boeing.

FHI shares aircraft manufacturing with other companies as well as developing its own aircraft. FHI produces the Fuji-Bell 205 B commercial lift helicopter under license from Bell Helicopter Textron. It also manufactures the A-5 turboprop light trainer for the Japan Maritime Self Defense Forces. The Fuji Bell AH-15 single engine anti-tank helicopter is manufactured by FHI under license from Bell Helicopte Textron. FHI is also engaged in producing aircraft simulators for the Japanese military.

ShinMayawa Industries Ltd. produces the US-1A STOL amphibian search and rescue airplane.

3.0 NATIONAL AEROSPACE LABORATORY

The National Aerospace Laboratory (NAL) was established in July 1955 as the National Aeronautical Laboratory and a subsidiary organization of the Prime Minister's office to expedite the development of Aeronautical Technology in Japan. In 1956 NAL was placed under the auspices of the Science and Technology Administration in the Prime Minister's office. In 1963, NAL was charged with the additional task of conducting research in space technology and given its present name. Its charter was then broadened to include conducting research and investigations that advance aeronautics and space technology, and to provide large-scale test facilities to be shared with other governmental organizations.

To broaden its research and development activities, NAL established its rocket research division in 1963 and its Kakuda Research Center in 1966. The Rocket Division was reorganized into the Space Technology Research Group in 1969 to allow for more effective space research with a stronger and more fully substantiated organization. NAL remains the home to the largest and most advanced aeronautical testing facilities in Japan. NAL has strong connections with NASDA where jointly they conduct various experiments essential for space development.

All of the research and test facilities at NAL are located on two main sites, the Headquarter site in Chofu and the Kakuda Research Center. All of the research and development and the administrative work is distributed among twelve divisions and two groups. Seven divisions and one group deal mainly with research and development in aeronautics, while two divisions and one group are concerned with space-related activities. Two divisions, namely the Thermofluid Dynamics division and the Computational Sciences division, support all aerospace efforts at NAL. The remaining division deals with administrative matters. However, there is a considerable amount of exchange of effort in space and aeronautics tasks between the different specialty divisions. NAL employs 434 individuals, 334 of whom are engaged in research and development with 100 administrators. One hundred and fifty three individuals possess advanced degrees, including 93 with Doctorate degrees and 60 with Masters. Figure 3 gives the listing of all of the divisions that are active in aerospace research and development at NAL.

Since NAL is considered the major center for research and development in aerospace technology, it possesses the most sophisticated testing facilities including the largest and most advanced wind tunnels and engine test facilities. The major wind tunnels located at NAL span all flow regimes and include hypersonic, supersonic, transonic, and low-speed wind tunnels, which are discussed in greater detail below.

3.1 HYPERSONIC WIND TUNNEL FACILITY

The hypersonic wind tunnel facility has been operating at NAL since 1964 with a recently added new leg soon becoming operational. The present facility comprises two wind tunnels, each with a different range and size, but both supported and served by a common infrastructure. Both tunnels use the same air supply in which the air is heated by the same pebble bed heater. The facility consists of the original 50 × 50 cm test section and a soon to be operational 127 × 127 cm test section. The smaller test section has four separate nozzles for operating at Mach Nos. 5, 7, 9, and 11 with a Reynolds number range of $0.7 \leq Re \leq 2 \times 10^6$ at $M = 9$. The operational stagnation pressure range, P_0, for this tunnel is $1 \leq P_0 \leq 10$ MPa, and a stagnation temperature range, T_0, of $600 \leq T_0 \leq 1500$ K. The inlet air to the test section is heated to the operational stagnation temperature using a pebble bed heater, which is comprised of aluminum microspheres that are capable of raising the air temperature to the required 1500 K. Both tunnels are blowdown type making the run times very limited, approximately 2-min maximum run time for the smaller test section tunnel.

The larger test section was built for the same operational characteristics as the AEDC Tunnel C, which has the same test section size of 127 cm and operational Mach number of $M = 10$. This tunnel has a single nozzle with exit diameter, *D*, of 127 cm. However, the major difference between the two is that the NAL tunnel has a maximum run time of 30 sec with a minimum of 1 hr between runs for preparation, while the AEDC tunnel is continuous. This tunnel has a Reynolds number range of $0.3 \leq Re/D \leq 4.5 \times 10^6$, $1 \leq P_0 \leq 10$ MPa, and $600 \leq T_0 \leq 1200$ K. The air heating system for this tunnel is augmented with the use of an air jacket duct heater up to the test section. At the present time, the tunnel can achieve a maximum of five runs per day by augmenting the pressurized air storage tanks with a vacuum tank and a pressurization pump.

The hypersonic test facility has all the appropriate diagnostic instrumentation including two types of model support stings. The lower main sting has three-degree-of-freedom support and rises into the flow field in approximately 1.6 sec. The upper sting is a shot type that is lowered into the flow field in 0.2 sec and is mainly used for thermal measurements. This sting is lowered quickly in order to avoid the formation of a boundary layer on the model. The diagnostic system includes a complement of three infrared cameras that are used for thermal measurements through imagery. The images from the cameras are fed into a dedicated computer that produces the temperature data in almost real time as the run is taking place. Work is underway to develop an actual real-time scan of the full model. Force and pressure measurements are accomplished using the lower sting. The hypersonic tunnel facility is highly computerized requiring only two operators for performing and monitoring the tests from a highly sophisticated control room. Figure 4 shows a schematic diagram of the hypersonic wind tunnel facility at NAL.

The major drawback of the larger test section is the short test run time of a maximum of 30 sec compared to the many hours of run time available at the AEDC Tunnel C. Also, the air for both tunnels is contaminated with aluminum microparticles which are stripped from the heating pebbles in spite of using microfilters for the air supply before it is admitted into the test section. However, Japanese researchers are able to accommodate most of their hypersonic test requirements locally with this test facility, making them independent of any foreign country. This constitutes a tremendous advantage for Japanese research and development in aeronautics.

3.2 SHOCK TUNNEL FACILITY

This is a mid-size shock tunnel that is located at Chofu and is much smaller than the larger shock tunnel facility presently under construction at the NAL's Kakuda Research Center. The Kakuda shock tunnel will be described in Section 3.8 below. This is a new facility whose construction has just been completed and is presently undergoing diagnostic evaluation.

The mid-size shock tunnel is designed to operate in the usual shock tunnel mode with a diaphragm, as well as in the QUIC mode without a diaphragm. In the QUIC mode the test section Mach number is obtained through a complicated arrangement of a piston driver and high-pressure annular ducting (see Ref. 3). Both modes of operation use the same test section. The tunnel is designed to operate at a test Mach number range of $10 \leq M \leq 15$ in both modes. The operational stagnation enthalpy is approximately 9 MJ/kg with a rarefaction parameter range of $0.02 \leq V_\infty \leq 0.1$, and a Reynolds number range of $2 \times 10^3 \leq Re \leq 3 \times 10^5\ r_e$, where r_e is the nozzle exit radius. The test duration in the regular mode is approximately 2 msec, while in the QUIC mode it is 100 msec. However, the maximum operational stagnation temperature in the QUIC mode is 2500 K, while in the normal mode it can be as high as 8000 K.

A schlieren system is used for recording the flow-field images. A 48 channel data acquisition system is used in this facility for monitoring the model pressure distribution as well as for monitoring the temperature and the force and moment distributions. Semi-conductor strain-gauge balances are used for measuring the forces and moments. This shock tunnel facility is fully automated requiring only two operators for executing the tests. Figure 5 shows a schematic of the NAL mid-size shock tunnel.

3.3 ARC TUNNEL FACILITY

This facility has undergone a major renovation and upgrading that has just been completed. The original arc-heated wind tunnel became operational in 1982. The arc-heated wind tunnel is a facility designed to produce high enthalpy hypersonic flow by electrically heating the gas and accelerating it through the nozzle. The purpose for this type of tunnel is to

simulate the reentry environment on models. The most common use of such a facility is for testing the degradation extent of materials as they are subjected to reentry environment. The upgrade of this facility involved increasing the operational power input from 450 kW to 750 kW. The modification of the facility includes the installation of a new, high performance, segmented arc heater; new conical and channel nozzles; a new water-cooled diffuser; new air heat exchanger, and additional vacuum pumps.

The upgraded arc-heated wind tunnel uses a single fixed nozzle with a throat diameter of 25 mm and an exit jet diameter of 115 mm and is capable of operating at a Mach number of 4.7. The flow rate in this tunnel can be varied from 8 to 22 kg/sec with a stagnation pressure of 1.2 atmospheres and maximum enthalpy of 25 MJ/kg at a maximum efficiency of 50 percent. The tunnel can run continuously for approximately 20 min.

The main instrumentation in the test section includes the model support system, which injects the model and probes into the flow stream, pitot tube traversing mechanism, and observation windows for infrared and flow monitoring cameras. The diffuser occupies the central portion of the chamber, which allows the catchcorn to be positioned near the nozzle exit for maintaining an effective blockage ratio. The model support system positions the model 100 mm downstream of the conical nozzle exit plane. Surface temperature measurements of the sample are accomplished by using a TVD camera that views the surface directly through the observation windows.

3.4 SUPERSONIC WIND TUNNEL FACILITY

The supersonic wind tunnel facility is the largest facility of its kind in Japan and has been in operation since 1961. Its basic design characteristics are similar to the AEDC Tunnel A supersonic wind tunnel. The test section for this tunnel is $1 \text{ m} \times 1 \text{ m}$, with a variable, two-dimensional nozzle design capable of operating in the Mach number range of $1.4 \leq M \leq 4.0$. Its operating Reynolds number range is $0.6 \leq Re \leq 1.8 \times 10^7$/ft with a maximum flow rate of approximately 300 kg/sec. Total pressure operating range is $152 \leq P_0 \leq 1275/kPa$, with a dynamic pressure range of 65 to 155 kPa. The tunnel operates at ambient total temperature. This is an intermittent, blowdown tunnel with a maximum run time of 60 sec with a variable model angle of attack. The minimum preparation time for another run is 20 min after the previous run, under ideal conditions. The latest upgrading for the tunnel was completed in 1988. The tunnel uses a second throat placed downstream of the test section for the purpose of lowering the exhaust air speed isentropically. A Helmholtz resonator is placed at the exhaust end, topped by a bypass resonator and a silencer to reduce the exhaust noise during the test run. Figure 6 shows a schematic of the supersonic wind tunnel facility at NAL.

This tunnel is capable of conducting force measurements using two six-component strain-gauge balances, and pressure measurements using Scanivalves® and electric scanning pressure transducers. Flow visualization is accomplished using color schlieren, vapor screen, and oil streaks. The tunnel has a 36 channel A/D data acquisition system and 12 digital inputs that are recorded and reduced in an on-line operation using an ECLIPSE-S 140 computer. All of the data collected from the tunnel during a single run can be reduced to graphical form in approximately 5 min after the test using a dedicated computer. The model angle of attack can be varied between −10 and 10 deg during the test, while for wider angle-of-attack requirements of up to 40 deg, a bent sting can be employed. The model sting for this tunnel has no roll capability during the test operation. This tunnel has some novel features incorporated for test improvements such as winglets attached to the nozzle wall for eliminating the shock interaction with the wall boundary layer. A major deficiency of the wind tunnel is the level of turbulence generated in the air, making it of poor air quality.

3.5 TRANSONIC WIND TUNNEL FACILITY

There are two major transonic wind tunnels at NAL. One is a two-dimensional tunnel and the other is a fully three-dimensional tunnel. The present three-dimensional transonic wind tunnel is the largest of the two facilities at NAL with test section dimensions of 2 m × 2 m and 4.13 m long. The wind tunnel Mach number range is $0.1 \leq M \leq 1.40$. The tunnel test section is interchangeable with three different types of test sections. This tunnel has been undergoing major overhaul and refurbishment to upgrade its capabilities since 1985. The upgrade effort has just been completed, and the wind tunnel is presently operational with its new capabilities. This is the largest transonic wind tunnel at the present time in Japan

The transonic facility is a closed-circuit, single return variable density tunnel with electrically motor-driven blowers for continuous operation. The maximum Reynolds number possible in this tunnel is 3.8×10^6 at $M = 0.9$. The operational stagnation pressure range is $40 \leq P_0 \leq 150$ *kPa*, and a stagnation temperature range of $40 \leq T_0 \leq 60$°C with a temperature control capability of ±1.0°C. The air quality has been improved in this tunnel with the aid of three screens (each with 14 mesh) for the purpose of reducing the turbulence level which at the present time stands at 0.2 percent in mass-flow fluctuations at $M = 0.8$. Figure 7 shows a schematic of the largest transonic wind tunnel at NAL.

Three interchangeable test section carts can be used in this tunnel. One cart is used for full-span model tests in which the model is supported by a sting-strut system and is used when force and pressure measurements are required. This cart provides for model angle of-attack range of -20 deg $\leq \alpha \leq 20$ deg, with the roll angle ranging between −180 and 180 deg and a data collection rate capability of 400 data points per day for the force balance tests. The walls in this

cart are perforated with hole axes normal to the wall and adjustable perforations for operating between 0- and 20-percent open-area ratio. Another cart is used for semi-span model tests in which the model is attached to an external balance system housed under the test section floor. All of the four surrounding walls have perforations with hole axes normal to the walls, and the open-area ratio in this test section is fixed at 20 percent. The third cart is used for various purposes. The upper and lower walls of the test section are slotted with the open-area ratio fixed at 6 percent. All four walls in this cart have glass windows for the purpose of observing the model during the test. The complete model could be supported in this cart using a sting-strut system for force and pressure measurements, and also a semi-span model could be supported using a special support system mounted on one of the walls for performing unsteady flow measurements. Also, semi-span model oscillation tests can be conducted with this cart for unsteady flow experiments. A flutter suppression plate is available in this cart for flutter tests.

The two-dimensional transonic wind tunnel has a smaller test section measuring 100 cm × 30 cm, and is capable of speeds in the range of $0.2 \leq M \leq 1.15$. This tunnel became operational in 1979 and is being renovated and upgraded at the present time. This wind tunnel is used primarily for conducting airfoil performance studies. It is also a blowdown wind tunnel with a minimum time requirement of one-half hour between runs. This is quite a unique wind tunnel which is capable of operating in the Reynolds number range of $6 \leq Re \leq 40 \times 10^6$. The instrumentation for this wind tunnel includes a color schlieren, and a 70 channel wake rake for spanning the wake pressure behind the airfoil. Also, temperature-sensitive liquid crystal paint can be used in this tunnel for performing flow visualization studies. The airfoil angle of attack can be varied in the tunnel from −15 to 25 deg with a maximum allowable model chord length of 25 cm. A force balance system is rarely used in this wind tunnel.

This tunnel is being upgraded and refurbished at the present time to increase its test section dimensions to 45 cm × 80 cm. The new test section will allow testing of three-dimensional models. The upgrading process will also include reducing the air turbulence level in the core to approximately 0.3 percent.

3.6 CRYOGENIC TRANSONIC WIND TUNNEL FACILITY

The cryogenic transonic wind tunnel facility at NAL is a single cryogenic wind tunnel with a 10 cm × 10 cm test section that is 30 cm long. The wind tunnel has been operational since 1984 with an operating Mach number range of $0.3 \leq M \leq 1.02$, a nominal stagnation pressure of 200 kPa, and a stagnation temperature of 100 K. This tunnel can operate continuously for up to 6 hr, a time only limited by the amount of stored LN_2. The tunnel has a liquid nitrogen reservoir capable of storing 2000 liters of LN_2 at five bars of pressure. The LN_2 nsumption rate is approximately 20 *l*/min. The tunnel must be purged and cooled before subsequent operation. The flow quality in

this tunnel is similar to the large transonic tunnel except this tunnel has larger stagnation temperature fluctuations.

Researchers at NAL are developing a unique instrumentation system for this tunnel that employs magnetic suspension for a balance system. The magnetic suspension balance system provides an ideal mechanism for supporting models in wind tunnel tests since the forces and moments necessary for supporting the model are generated by a magnetic field through coils placed outside the test section. All balance interference with the model is eliminated in this way since all of the conventional mechanical supports are eliminated using this method. The details of such a support system for a 10 cm × 10 cm test section are given in Ref. 4. This method is currently being implemented for a 60 cm × 60 cm test section. Other instrumentation for this wind tunnel includes a heated and thermally insulated force system and a 48 channel Scanivalve for pressure measurements.

3.7 LOW-SPEED WIND TUNNEL FACILITY

The low-speed test facility at NAL is the largest of its kind in Japan. The test facility is a low-speed wind tunnel with a test section measuring 6.5 m × 5.5 m × 9.25 m. This tunnel became operational in 1965. The tunnel is a single return Gottingen-type design capable of delivering the air at a maximum speed of 75 m/sec. The tunnel in its present configuration has a motor driven belt for simulating a moving floor that is capable of achieving a maximum speed of 50 m/sec. The tunnel has recently undergone major refurbishment and upgrade including installing a new test section. As a result, a substantial improvement in the turbulence level to approximately 0.2 percent is now possible in the tunnel. The instrumentation for the tunnel includes the usual force and moment balances operating with the aid of a captive trajectory system. Also, the tunnel has large windows for flow-field observations. Since it is the largest wind tunnel of its kind in Japan, it is heavily used with approximately 50 percent of its usage coming from outside sources and the remaining 50 percent by researchers from NAL.

3.8 ENGINE TEST FACILITY – KAKUDA RESEARCH CENTER

All of the space propulsion research and development activities at NAL are conducted at the Kakuda Research Center (KRC). The Kakuda Research Center houses the Rocket Propulsion and the Ramjet Propulsion Divisions which employ approximately 60 individuals. Although KRC is primarily a research center and not a test center, it nevertheless possesses the most advanced space propulsion test facilities in Japan. Because of its status, KRC has very close working relationships with a number of universities in Japan, especially with Tohoku University. KRC hosts a number of graduate students who are performing their research activities towards a graduate degree. There is always at least one graduate student in residence at any time. Among the major research activities

currently active at the KRC are (1) oxygen-hydrogen rocket engine components including high-pressure combustors and turbopumps, (2) aerospace plane engines including ramjet engine performance, combustion, and cooling structures, (3) rocket engine systems, (4) rocket engine high altitude performance, (5) functionally gradient materials, and (6) rocket engine element flow analysis. Figure 8 shows the research and development organizational structure at KRC.

Two of the largest and unique test facilities operating at the present time at KRC are the Ramjet engine test facility, and the subscale Free Piston Shock Tunnel. The Ramjet test facility became operational in 1993 and can operate in three different Mach number regimes, M = 4, M = 6, and M = 8. For the M = 4 regime, the test conditions include 20 km altitude simulation, capable of 217 K static temperature and 5528 Pa static pressure. This tunnel uses a storage air heating system and can sustain a maximum test duration of 60 sec. The M = 6 regime test conditions include 25 km altitude simulation, operating at 222 K static temperature and 2549 Pa static pressure; and it can operate in either vitiated air heating mode or storage air heating mode with a maximum test duration of 60 sec. The M = 8 regime test conditions include 35 km altitude, 237 K static temperature and 575 Pa static pressure. It employs simultaneously vitiated and storage air heating modes, with a maximum operation duration of 30 sec. Figure 9 shows a schematic of the ramjet test facility at KRC.

The Free Piston High Enthalpy Shock Tunnel (HIEST) is scheduled to be operational in 1997 with the construction contract being awarded in June 1995. The design specifications for the NAL HIEST facility include a 42-m compression tube, a 17-m shock tube, with five pistons capable of delivering 370 to 895 kg, and nozzles capable of 6 to 10 Mach. The HIEST test duration is 2 msec with stagnation enthalpy of 25 MJ/kg and stagnation pressure of 150 MPa. Figure 10 shows a schematic of the proposed design configuration for the HIEST facility at KRC. A subscale HIEST tunnel is currently operational at KRC.

3.9 NUMERICAL SIMULATION FACILITY

The two most essential tools necessary for conducting aerospace research and development are the wind tunnels with their wide range of capabilities as well as computational facilities. Computational mechanics, including both structural dynamics and fluid dynamics, has been essential for the development of the various components of aerospace technology. With the huge improvements in the computational capabilities of present day computing machines, aerospace scientists and engineers have become dependent on computers for performing most of their research and development activities. Computational mechanics is considered at the present time a necessary enabling technology for aerospace research and development. For this reason NAL attaches great importance to its Computational Sciences Division and considers it an important and integral component of its aerodynamic facilities' infrastructure.

Recent progress in Computational Fluid Dynamics (CFD) brings to the realm of possibility the performance of realistic three-dimensional viscous flow simulations around a full aircraft as well as through compressors and turbines. Results from numerical simulations at critical design points of aircraft show good quantitative agreement with experimental data obtained from conventional wind tunnels. Three-dimensional viscous flow simulations are also employed for developing turbine blades. Also, physically complex flow simulations, such as reacting flows in combustors and hypersonic flows with real gas effects, are within the realm of computational possibility at the present time.

Although CFD research activities are producing excellent results, there are many problems to be resolved. In order for results from numerical simulations to provide good agreement with experimental data, long computational times are necessary. Computational times of the order of 10 hr are required on a high-speed computer such as the Fujitsu VP400 (1.14 Gflops peak) which is the former supercomputer at NAL. A realistic time estimate requirement for each simulation puts it at more than 1 hr per 100 thousand grid points. It is estimated that between 5 to 15 million grid points are necessary for simulating a complete aircraft configuration with its control surfaces. Such a number of grid points makes the use of numerical simulations for actual aircraft development purposes a prohibitive endeavor. That use translates into 50 to 150 hr necessary for a complete simulation on the VP400. For this reason NAL engaged in an ambitious numerical simulation plan that culminated in the establishment of the Numerical Simulator II.

The centerpiece of the Computational Sciences Division at NAL is the recently operational Numerical Simulator II facility. This facility is considered to be among the most powerful numerical simulation facilities in the world today. It is capable of dealing with various types of simulation needs in order to answer all demands from basic research to the application field. The Numerical Simulator II consists of a number of super computers that are networked together using a uniquely developed architecture. It is comprised of the Numerical Wind Tunnel (NWT), a Fujitsu VP2600 and VP2100, an INTEL Paragon, and a Cray®-MP supercomputer.

The NWT is a parallel supercomputer with a specially designed distributed memory architecture derived from analyses based on CFD codes developed at NAL. The NWT was developed through a joint research effort between NAL and Fujitsu. It is comprised of 140 vector processing elements (PE) connected by a high-speed crossbar network. Each individual processing element is comprised of 121 microchips. The performance of each individual processing element is 1.7 GFLOPS, which is equivalent to that of a supercomputer by itself but having the size of a pizza box. Each processing element has a main memory of 256 MB. A high-speed crossbar network connects the 140 PEs. The PEs are equally laid out on this network. The total peak performance of the NWT is 236 GFLOPS. The total capacity of the main memory is as great as 35 GB. The NWT can be expanded by accommodating additional processing elements that enable it to increase its performance to several hundred GFLOPS. Figure 11 shows a schematic of the general computational system configuration for the Numerical Simulator II facility at NAL. The NWT performance is being continuously assessed against other supercomputers by running a

common computational exercise. Its maximum speed has been assessed at 170.4 GFLOPS when running the full 140 processing units. With this speed the NWT was rated by J. J. Dongarra of the University of Tennessee (Ref. 5) in August of 1994 as the fastest parallel computer in the world.

The Numerical Simulator II facility is being extensively used for CFD calculations since it became operational in 1993. Many computationally intensive fluid dynamics calculations are being performed including numerical simulation of flows around aircraft and numerical simulation of flows around space planes such as aerothermodynamics design for the HOPE vehicle. Other applications include the numerical simulation of supersonic flows around the combined HOPE-H II rocket, oxygen mole fraction distribution around the HYFLEX vehicle at hypersonic reentry conditions, and numerical simulation of non-equilibrium flow in an arc heated wind tunnel. The numerical simulator is also being used for basic research in fluid dynamics such as predicting the laminar-turbulent transition process and numerical simulation of turbulence.

4.0 JAPAN DEFENSE AGENCY

The Japan Defense Agency (JDA), a government organization that reports directly to the Prime Minister, also has aerospace test facilities. One of the organizations that makes up the JDA, the Technical Research and Development Institute (TRDI), conducts research, development, test and evaluation of military systems and equipment such as fighting vehicles, ships, aircraft, and guided weapons for ground, maritime and air self defense forces. Dr. Mashiro Ohta is presently the Director General of TRDI.

The organization within TRDI that has responsibility for research on aircraft, aircraft engines, missiles and rocket engines is the Third Research Center (TRC), whose headquarters are located on a 62 acre tract in the East Tachikawa Post on the western outskirts of Tokyo. Employing approximately 200 people, TRC has three divisions: one for study, research and testing of airframes, one for propulsion systems, and one for research and test of missile and avionics systems. Dr. Naminosuke Kobota is the Director of the Third Research Center.

TRC has two large test facilities in the Tachikawa area. One is a convertible wind tunnel, which is capable of operating both as a continuous flow, single-return horizontal subsonic wind tunnel and as a continuous flow, open-circuit vertical subsonic wind tunnel. The horizontal tunnel has two horizontal test sections: one is 3.3 × 3.3 × 4.5 m and uses a strut-type balance for six-component force tests; the other is 6 × 6 × 6.25 m and is used for large model tests. The vertical tunnel is a 4-m octagon with a spin test section and a rotary balance apparatus, and is used for free-spin and aerodynamic tests.

The other facility at TRC is a continuous flow, single-return subsonic wind tunnel with a 2.5-m diam by 3.5-m long test section. The tunnel has a sting-support system used for six-component force tests and high angle-of-attack tests up to 90 deg. A wire-support system is used for external store separation and flutter tests.

TRC is constructing a new blowdown wind tunnel at the Sapporo Test Center in northern Japan. This facility is called a trisonics wind tunnel, which means it covers the subsonic, transonic, and supersonic regimes. Velocities range from Mach 0.3 to 4.0, with Reynolds number up to 1.08 $\times$ $10^8/m$. The test section is 2 m square. The run time is projected to be 10 sec, with 45 min necessary between runs. This facility is expected to be completed in the near future.

5.0 INDUSTRIAL RESEARCH AND DEVELOPMENT

5.1 MITSUBISHI HEAVY INDUSTRIES

Mitsubishi Heavy Industries (MHI) is the largest defense contractor in Japan, receiving over 20 percent of the total Japanese aerospace defense contract amount in FY94. The second largest contractor, Kawasaki Heavy Industries, only had 11 percent. MHI has research and manufacturing facilities at locations throughout Japan, including Nagasaki, Takasago, Kyoto and Nagoya. All of their wind tunnels are located in the Nagoya area.

Two wind tunnels are located at the Oye plant in Nagoya. The 2-m, low-speed wind tunnel, initially placed in operation in 1928, is the tunnel in which the famous WW II Zero fighter was developed. The tunnel has been upgraded several times since it was first built. The tunnel, which has a 1.8 × 2.0 × 2.5 m long test section, is a continuous-flow, closed-circuit, single return subsonic test facility. The wind tunnel Mach number range is 0.06 to 0.23. Both sting and strut supports are used to test models of aircraft, missiles, and helicopters. The facility can conduct force tests, pressure tests, half-model tests, power effects tests, wake measurements tests, and flow visualization tests. Angle-of-attack range is from −30 to 60 deg (sting-support) and −13 to 22 deg (strut-support).

The MHI Oye plant is also the location of the 60-cm transonic wind tunnel. This is an intermittent blow-down tunnel capable of conducting tests in the subsonic, transonic, and supersonic speed ranges. The test section is 0.6 × 0.6 × 2.8 m long. The Mach number range is 0.4 to 4.0 with a Reynolds number range of 15 to 65 million/m. The tunnel conducts force tests, pressure tests, half-model tests, flutter tests, static aeroelastic tests, air intake tests, power effect tests, and flow visualization tests. The angle-of-attack range is −15 to 30 deg (sting-support). Run times vary from 20 sec at Mach 1.0 to 35 sec at Mach 2.5.

MHI also has a low-speed smoke tunnel at the Komaki plant in Nagoya. This tunnel is a specialized induction, open-circuit, subsonic facility used for flow visualization tests by the smoke technique. The test section is 0.2 × 1.5 × 2.5 m long. Wind speeds are 0.11 m/sec or 40 m/sec for

pressure and force tests and 0.05 m/sec or 18 m/sec for smoke visualization tests. Smoke is provided by kerosene vapor in 69 lines. The tunnel is used not only for low-speed aerodynamic studies but also for testing such things as airflow through automobile radiators and development of flowmeters.

5.2 KAWASAKI HEAVY INDUSTRIES

Kawasaki Heavy Industries (KHI) is a diverse company, developing and manufacturing everything from high-speed trains to motorcycles. KHI builds the world-famous Shinkansen, or "bullet train"; energy plants using such things as gas turbines; jet skis for recreation; recycling systems that will handle a variety of materials; all types of ships including the ultrahigh-speed passenger ship "Kawasaki Jetfoil"; and, of course, aircraft and jet engines. KHI builds portions of the Boeing 777 and 767, and manufactures the T-4 intermediate jet trainer and the P-3C antisubmarine patrol aircraft.

KHI's wind tunnels are located at the Gifu Works approximately 50 km north of Nagoya. Their facilities consist of three conventional wind tunnels, an acoustic test facility, and a low noise wind tunnel.

The KHI Low-Speed wind tunnel is a subsonic atmospheric wind tunnel with both closed and open test sections. The test section is $2.5 \times 2.5 \times 3$ m long (open) and $3.5 \times 3.5 \times 6.5$ m long (closed). Mach number varies from 0 to 0.1 (closed) and 0 to 0.19 (open). The Reynolds number varies from 0 to 4.5×10^6/m. The open test section has an external six-component balance (strut mount) or internal six-component balance (sting mount). The closed test section has an external six-component balance with strut mount.

The Transonic wind tunnel is the blowdown type with a 1.0×1.0 m test section. Mach number varies from 0.2 to 1.4. Because of the high total pressure (5 atmospheres) the tunnel can achieve a Reynolds number of 72×10^6/m. The tunnel conducts six-component force and moment tests, half-model tests, and pressure tests. It is capable of exhaust jet simulation, schlieren flow visualization, and wake measurements. This is the largest transonic wind tunnel in Japanese industry with the highest Reynolds number of any wind tunnel in Japan.

KHI's Two Dimensional wind tunnel is also the blowdown type with a $10 \times 40 \times 100$ cm long test section. Mach number varies from 1.5 to 5 atmospheres, and Reynolds number varies from 18 to 78×10^6/m. The primary function of this wind tunnel is for performing fundamental research on airfoils.

KHI's Acoustic test facility has a 12×12 m test section, 160 Hz cut-off frequency, with 25 dB(A) background noise. It is used for jet noise reduction, fan noise reduction, rotor noise reduction, and machine noise measurement tests.

KHI's Low Noise wind tunnel has a 12 × 12 × 9 m high anechoic chamber and is used primarily for noise measurement tests, but can also conduct six-component force tests, pressure measurement tests, and flow visualization tests.

5.3 ISHIWAJIMA-HARIMA HEAVY INDUSTRIES

Ishiwajima-Harima Heavy Industries (IHI) is one of the five largest aerospace industries in Japan. IHI specializes in aircraft engines and is the only jet engine manufacturer in Japan. IHI's Aero-Engine and Space Operations specializes in the development and manufacture of aero-engines, space-related equipment, land/marine gas turbines, and aero-engine maintenance and repair. IHI's Aero-Engine and Space Operations represents approximately 16 percent of the total business of IHI with 80 percent of their sales for the Japanese military and the remaining 20 percent in civilian sales, which is mostly for engine overhaul and repair work.

IHI developed and produced its first jet engine, the J3, in 1959, the first totally Japanese jet engine. However, IHI had completed testing and development of its first jet engine one month before the end of WW II, but it was never produced. The J3 was followed later by licensed production of the J79, T64, T58 and TF40 engines. Recently IHI has added the F100, T56, F3, and the T700 to its production line. IHI has been involved in numerous engine development projects including the national project for the FJR70 and the Japan-Britain joint project for the RJ500. Currently, IHI is the leader of a five nation collaborative project for the development and manufacture of the V2500 engine. In addition, IHI overhauls and repairs engines from General Electric, Allison, Pratt and Whitney, and Rolls Royce. IHI is a co-developer with four other nations of the GE90 engine for the Boeing B777 aircraft.

IHI has been participating in NASDA's development projects since their early stages, playing an important role in the production of liquid-propellant rocket and attitude control motors. IHI is presently engaged in the development of LOX/LH2 turbopumps for the H-I and H-II all-Japanese rockets, and also in developing the attitude control systems for the second stage of the rockets and for satellites.

IHI is engaged in an aggressive research and development program in materials for engine blades such as fiber-reinforced ceramics and Silicone Carbide materials. Being an engine manufacturer, IHI has five engine test cells, two cells for thrust up to 20,000 lb, one each for up to 30,000, 60,000, and 100,000 lb. Every engine manufactured or overhauled by IHI is tested in one of these test cells before delivery to the customer. In addition, the research and development division possesses a water tunnel and facilities for engine components testing, including a fan rotation facility, fan containment facility, low cycle fatigue test facility, anechoic chamber for engine noise control, HYPER engine test facility for high-temperature air, and total fan test facility capable of testing engines rated up to 12,000 hp with plans to increase its test capabilities up to 18,000 hp in the near future.

5.4 FUJI HEAVY INDUSTRIES

Fuji Heavy Industries (FHI) is another one of the five major aerospace industries in Japan. Again, the sales from the aerospace business represent only 8 percent of the total sales for FHI. The aerospace technology specialty of FHI at the present time is in helicopters, aircraft body components and rockets, and trainers including training systems such as simulators. FHI is the prime contractor for the AH-1S antitank helicopter and developed and produced the T-5 as the basic trainer for the Japan Self Defense Force.

FHI was one of the partners in producing the YS-11, which was Japan's first post-war commercial transport. Also, FHI developed and produced the FA-200, a light, single engine airplane. FHI was involved in a cooperative venture with Rockwell International in developing the FA-300, a twin engine business airplane. At the present time FHI is participating in a number of international joint development projects including manufacturing the body/wing fairings and the Main Landing Gear doors for the YX/Boeing 767 and the YXX/Boeing 777, as well as supplying the center wing component for the YXX/Boeing 7J7.

The aerodynamic test facilities at FHI include a high-speed and a low-speed wind tunnel. The high-speed wind tunnel has a 60 cm × 60 cm test section and is capable of a speed range of $0.2 \leq M \leq 4.0$. The wind tunnel is a blow-down design with a maximum test time of 10 sec at M = 2 and employs chillers for air moisture reduction in the test section. The low-speed wind tunnel has a 2 m × 2 m × 3 m test section with air speed capability of up to 72 m/sec. The unique feature of this tunnel is the low turbulence level in the test section. Both of these tunnels are used for internal research and development and primarily used under contract from JDA.

6.0 CONCLUSIONS

The development of aerospace technology in Japan has been progressing steadily and in a deliberate and methodical manner since the lifting of the ban on research and development. The technology development in aerospace first began as a form of licensing production of the various aircraft parts and types. This is an efficient way of building the technology infrastructure and bypassing the massive and necessary investment in research and development. Japan was, and still is, producing under license jet engines, aircraft frames and indeed different types of military and civilian aircraft. At the same time it has been slowly building its research and development infrastructure by investing in testing facilities at national laboratories.

Aerospace technology has matured enough in Japan that the emphasis at the present time is on international partnership in aircraft production. This is also the future outlook of the aerospace industry in Japan. Japanese aerospace industry co-produces at the present time, with international

partners, the V2500 jet engine as well as components for the Boeing B767 and B777 aircrafts. At the same time the Japanese government is nurturing the development of several national large-scale aerospace projects including the V2500 engine, the YSX-100 aircraft, the HYPER project, and the HOPE vehicle.

The V2500 is an advanced technology turbofan engine, featuring low fuel consumption, low noise and low pollution, with a thrust range of 22,000 to 30,000 lb. The project was initially carried out between the Japanese Aero Engines Corp. and Rolls Royce, and later they were joined by United Technology Corp., Motoren-und Turbinen Union, and Fiat. The parts of the V2500 assigned to JAEC are the fan and the low-pressure compressor, and parts of the high-pressure compressor and turbine. The V2500 is used on the Airbus A320 and A321, and on the McDonnell Douglas MD-90. The V2500 will also be used on the all-Japanese airliner YSX-100.

The YSX-100 is a 100-seat, twin-engine, jet airliner to be developed by Japan aircraft industry utilizing the experience gained from the YS-11, the YX/B767 and B777. The decision to produce the YSX-100 was partly based on market forecasts of 2800 units needed by the year 2015 with 700 units to be retained. Some of the design specifications for the aircraft include a cruising speed of M = 0.75, a flight range of 4000 km, and a field length requirement of 2000 m. The feasibility study is now in progress to finalize aircraft specifications, performance, and development schedule with the first airplane delivery anticipated by the year 2000.

The HYPER project was initiated as Japan's response to the challenges of the next generation of supersonic transport as well as the hypersonic transport. It is a research and development program for the purpose of establishing the necessary technologies for the next generation Super/Hypersonic Transport Propulsion System. Such a system will allow a flight to go from the supersonic regime to Mach 5 with low fuel consumption, low noise, and reduced NOX emissions. Also the purpose of this program is to establish the technologies that will lead to the development of an energy-efficient gas turbine for electric power generation. The research and development program for this project began in 1989 with the active support of MITI and is expected to last for 10 yr. In its present configuration, the project is divided into five categories: the ramjet, the turbojet, the control and measuring system, the total system, and the ultrahigh temperature gas generator research and development.

The HOPE is an unmanned winged space transportation vehicle that is launched by an upgraded H-II rocket. The objectives of the HOPE program are to develop the capabilities of recovering satellites from orbit and to establish the basic technology for a completely reusable space transportation of the future. The program includes three small-scaled experiments and one full-scale demonstration flight in cooperation between NASDA and NAL. HOPE-X is scheduled to be launched around 1999 on an H-II.

These five major national programs in aerospace technology are being used as the main drivers for developing the necessary sophisticated test and computational facilities at the national level. It is apparent that the aerodynamic testing facilities at NAL represent the current state of the art in aerospace technology. All of the facilities should be considered among the best worldwide, which positions Japan on a competitive basis with both the United States and Europe in research and development capabilities in aerodynamics. Most of the wind tunnels belonging to NAL have either undergone major upgrade and refurbishment recently, or are scheduled for it. Generally, some of the wind tunnels at NAL have superior performance characteristics over comparable facilities at AEDC while others have inferior capabilities. However, it is evident that Japan is investing substantially into bringing its aerodynamic research and development infrastructure to meet high standards. The policy of pushing this investment is made at the highest governmental level, which is the ministerial level in Japan.

NAL, being a government laboratory, is dedicated to working together with academic institutions to support the aerospace technology needs of industry. There is substantial evidence that NAL works closely with industry, academia, and other government organizations. This is evidenced by the large number of personnel from both academia and industry that are usually present at NAL. In addition, personnel from these institutions participate fully with NAL scientists and engineers in developing the design operating criteria for most of the test and computational facilities at NAL. Such close partnership between the three elements is more often absent in the United States.

An interesting final observation with a personal note concerns the role played by Japanese academic institutions in the area of aerospace technology development. There was an evident lack of interaction between aerospace industry and academia. Rarely do faculty or students at a Japanese university perform contract work or consult with industry. The cause of this lack of cooperation was attributed to the nature of faculty responsibilities in Japan which are markedly different from their colleagues in the United States. This lack of interaction constitutes, in our opinion, a major shortcoming in the progress and development of aerospace technology in Japan.

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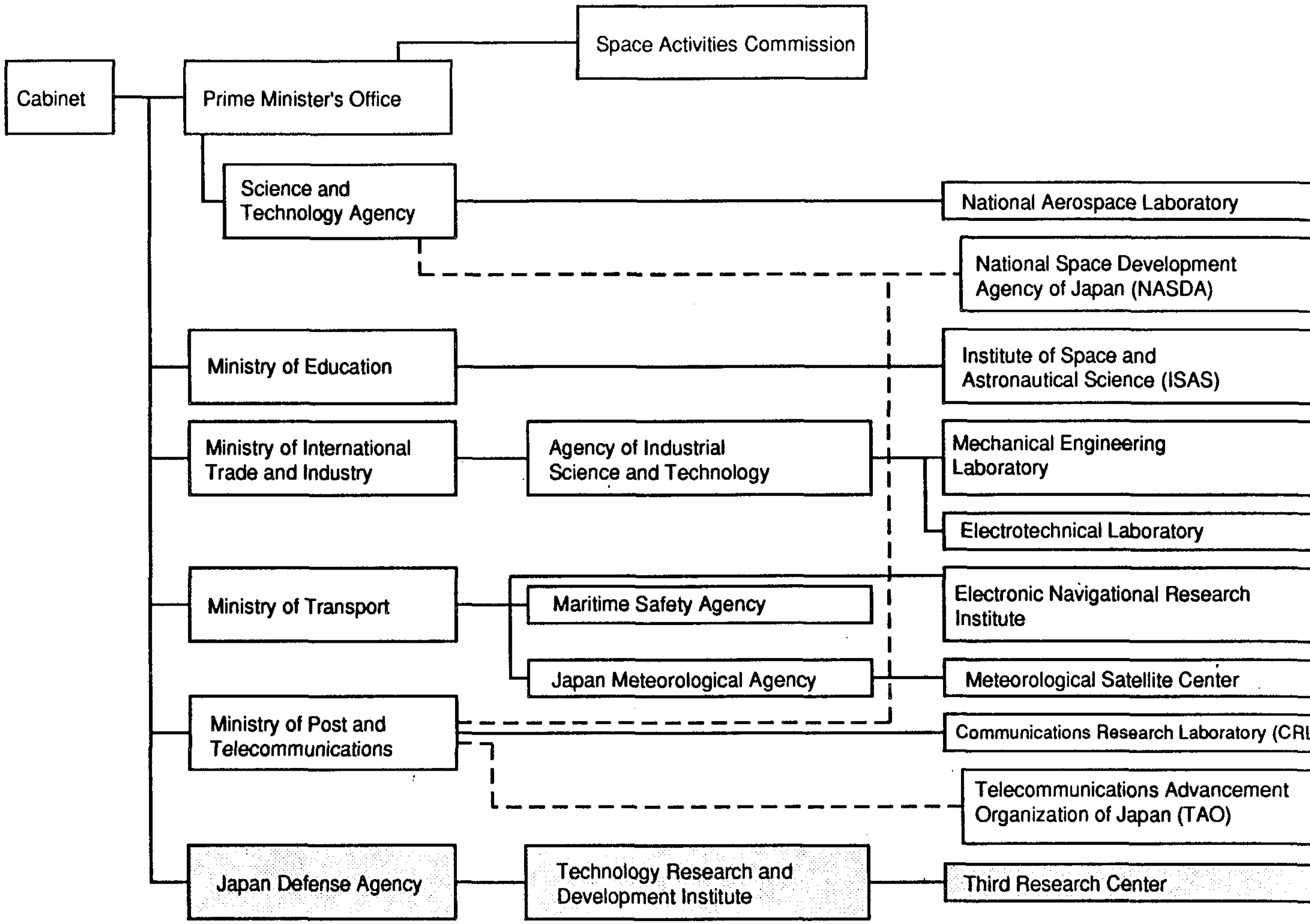


Figure 1. Chart showing government organizations involved in aerospace activities.

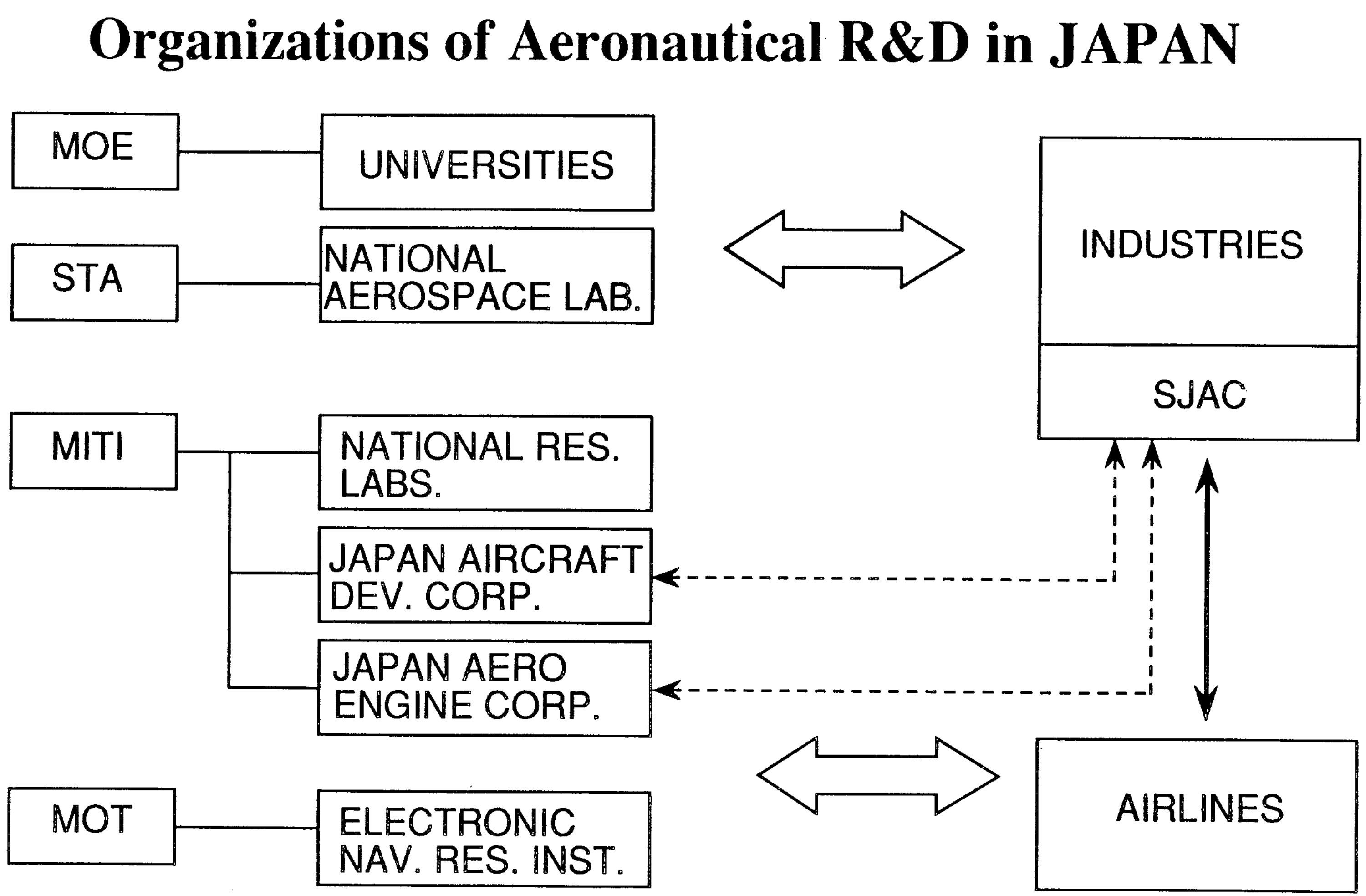


Figure 2. Chart showing Japanese organizations involved in aeronautical research and development.

NAL Research Organization Structure

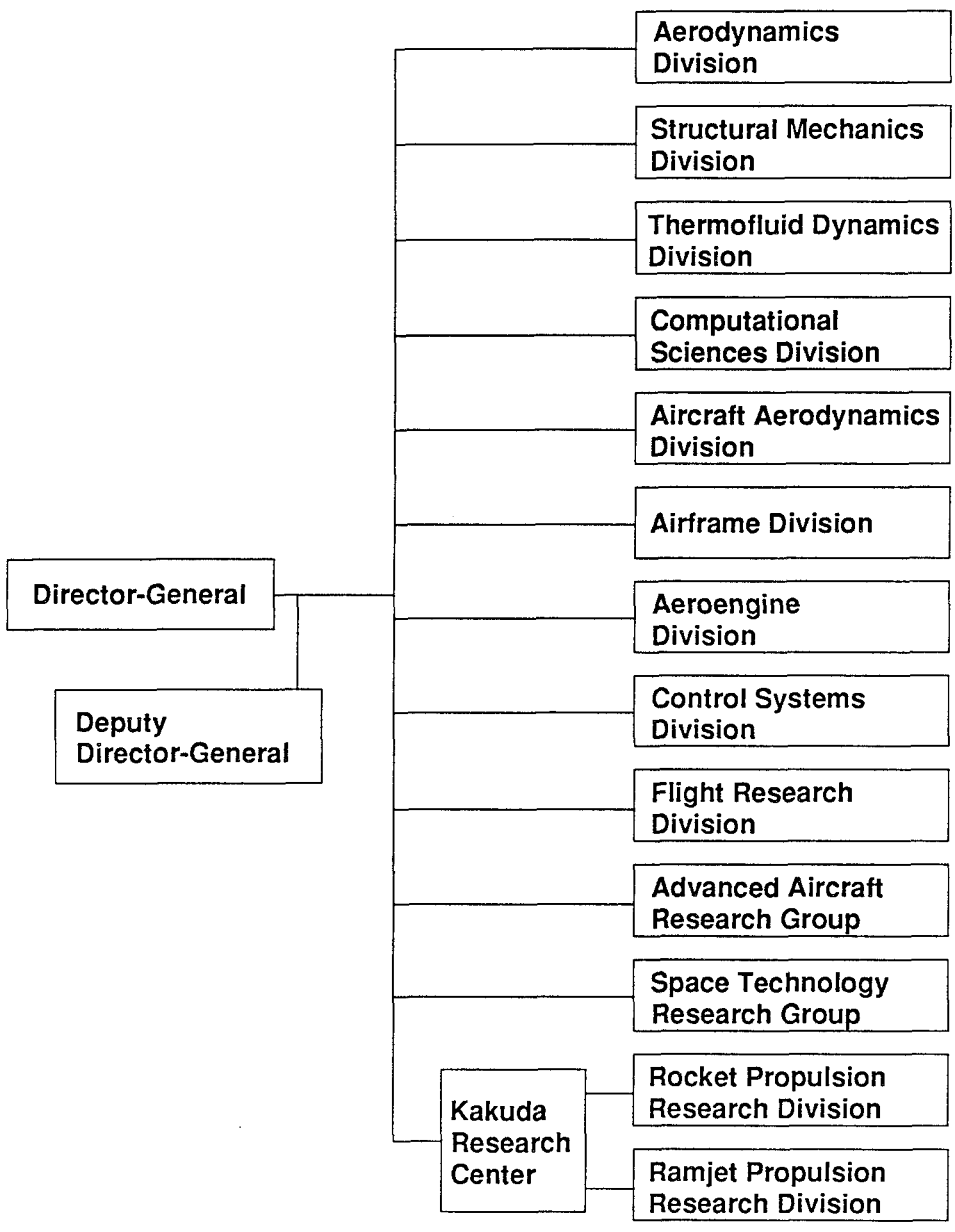


Figure 3. Organization chart for NAL.

Hypersonic Wind Tunnel System NAL JAPAN

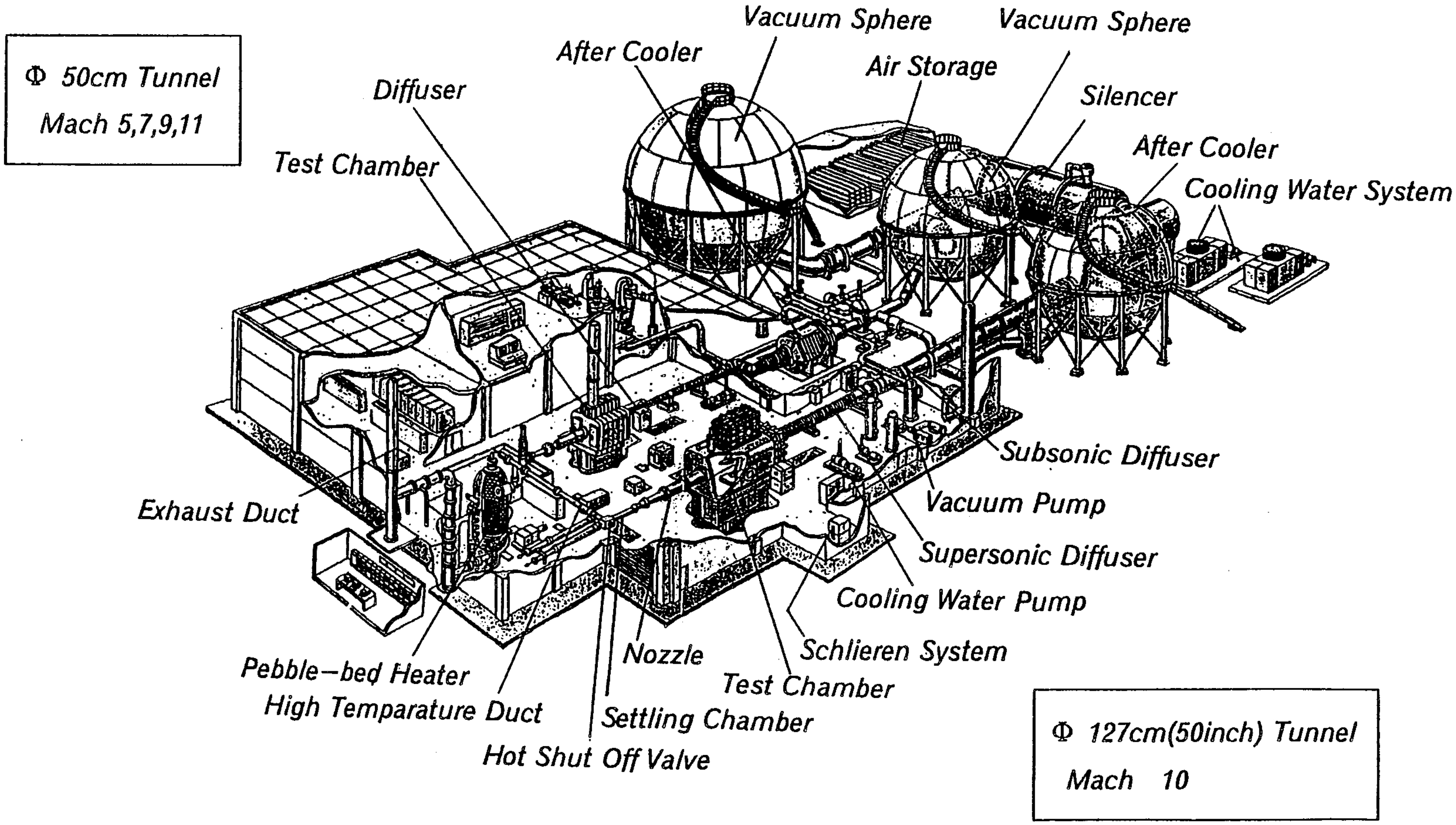


Figure 4. Layout of the hypersonic wind tunnel facility.

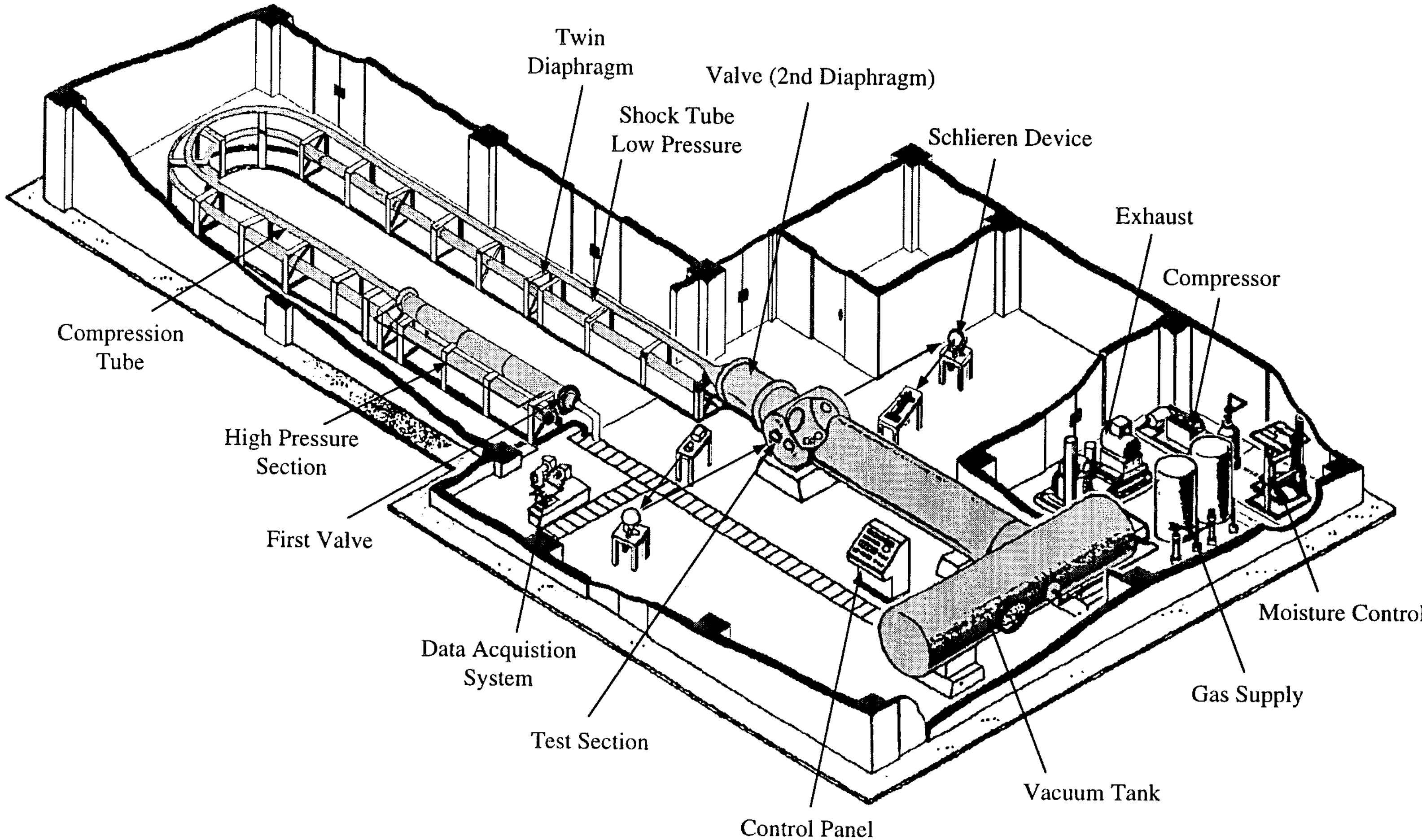


Figure 5. Layout of the mid-size shock tunnel facility.

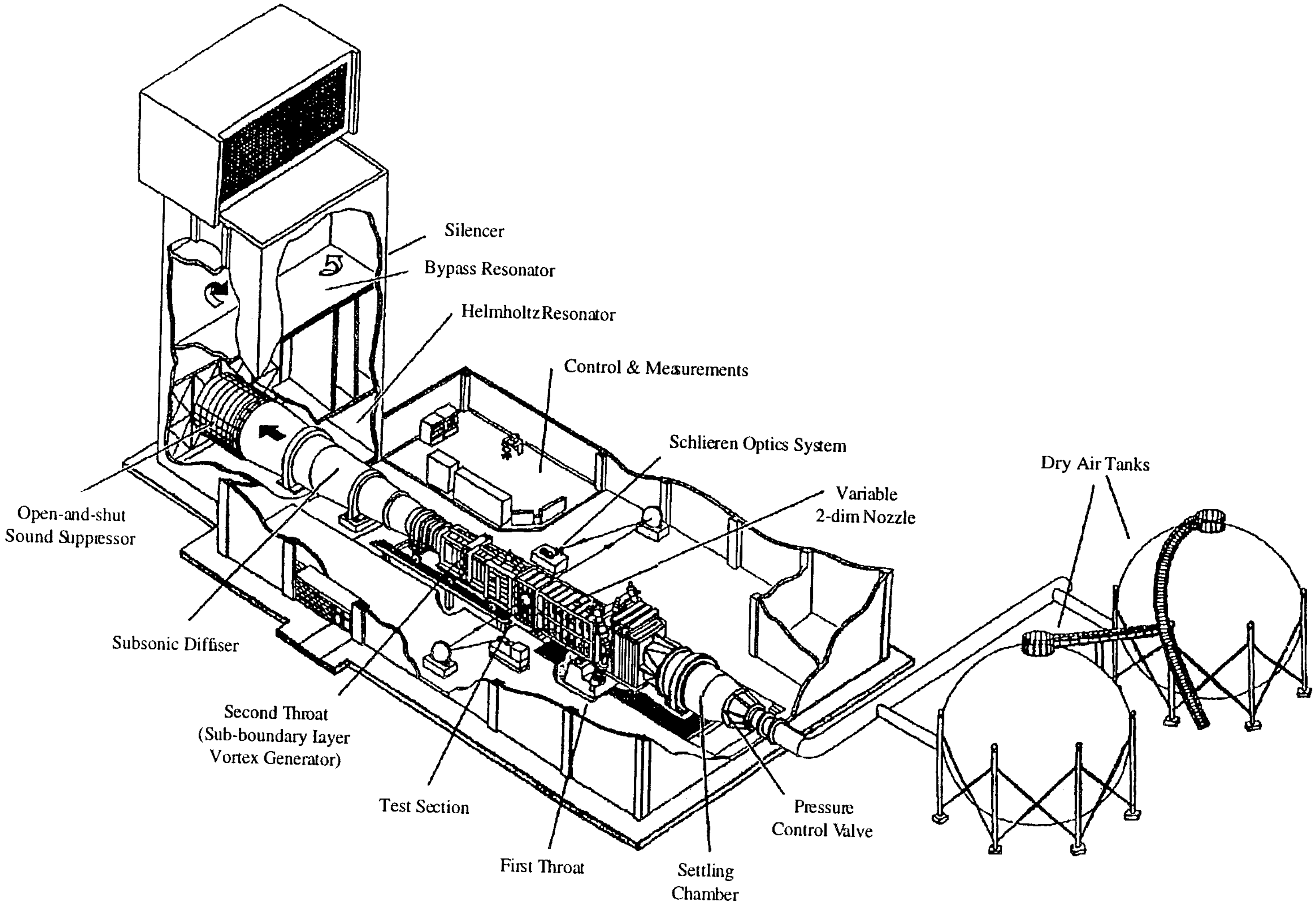
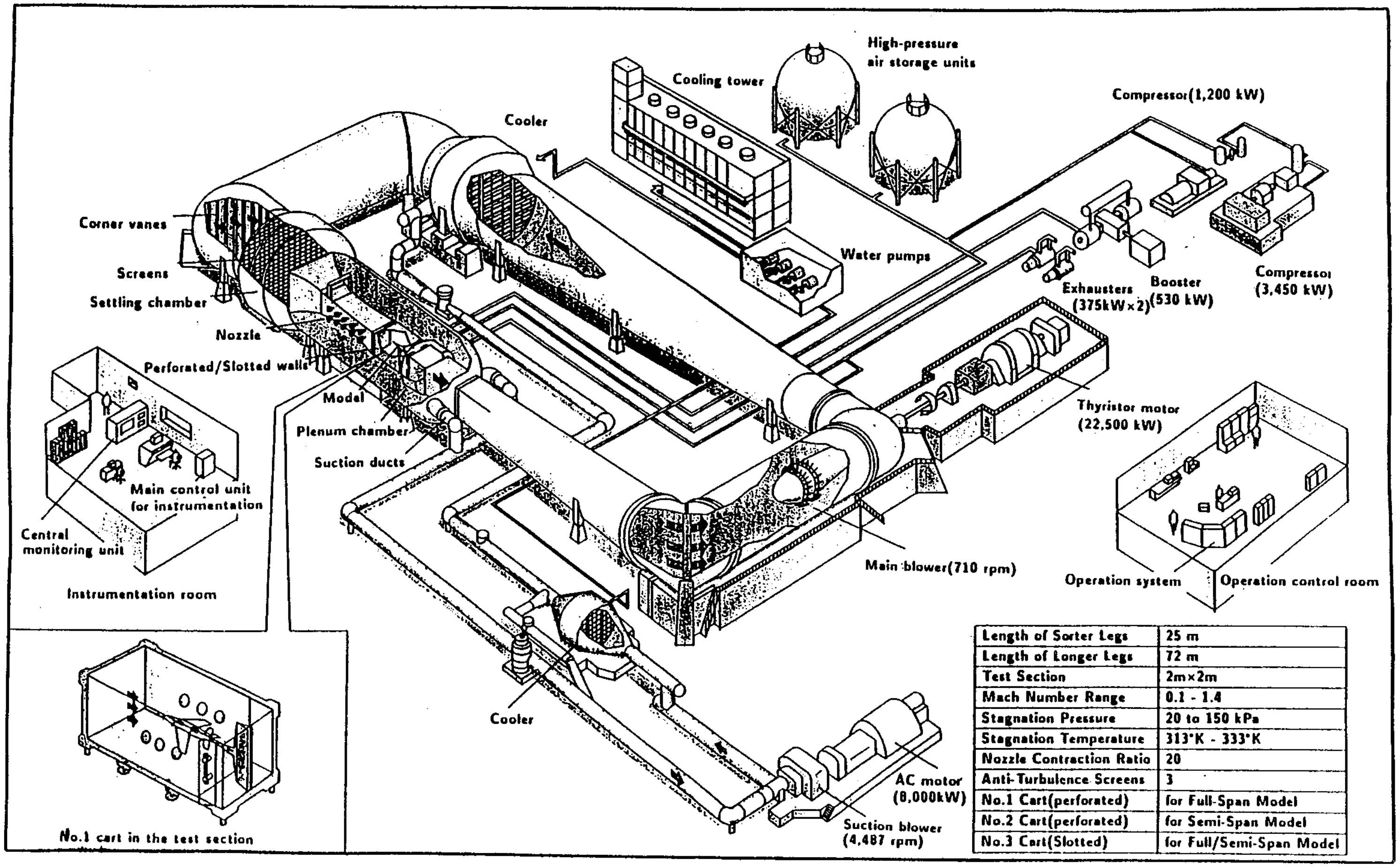


Figure 6. Layout of the supersonic wind tunnel facility.



Length of Sorter Legs	25 m
Length of Longer Legs	72 m
Test Section	2m×2m
Mach Number Range	0.1 - 1.4
Stagnation Pressure	20 to 150 kPa
Stagnation Temperature	313°K - 333°K
Nozzle Contraction Ratio	20
Anti-Turbulence Screens	3
No.1 Cart(perforated)	for Full-Span Model
No.2 Cart(perforated)	for Semi-Span Model
No.3 Cart(Slotted)	for Full/Semi-Span Model

Figure 7. Layout of the transonic wind tunnel facility.

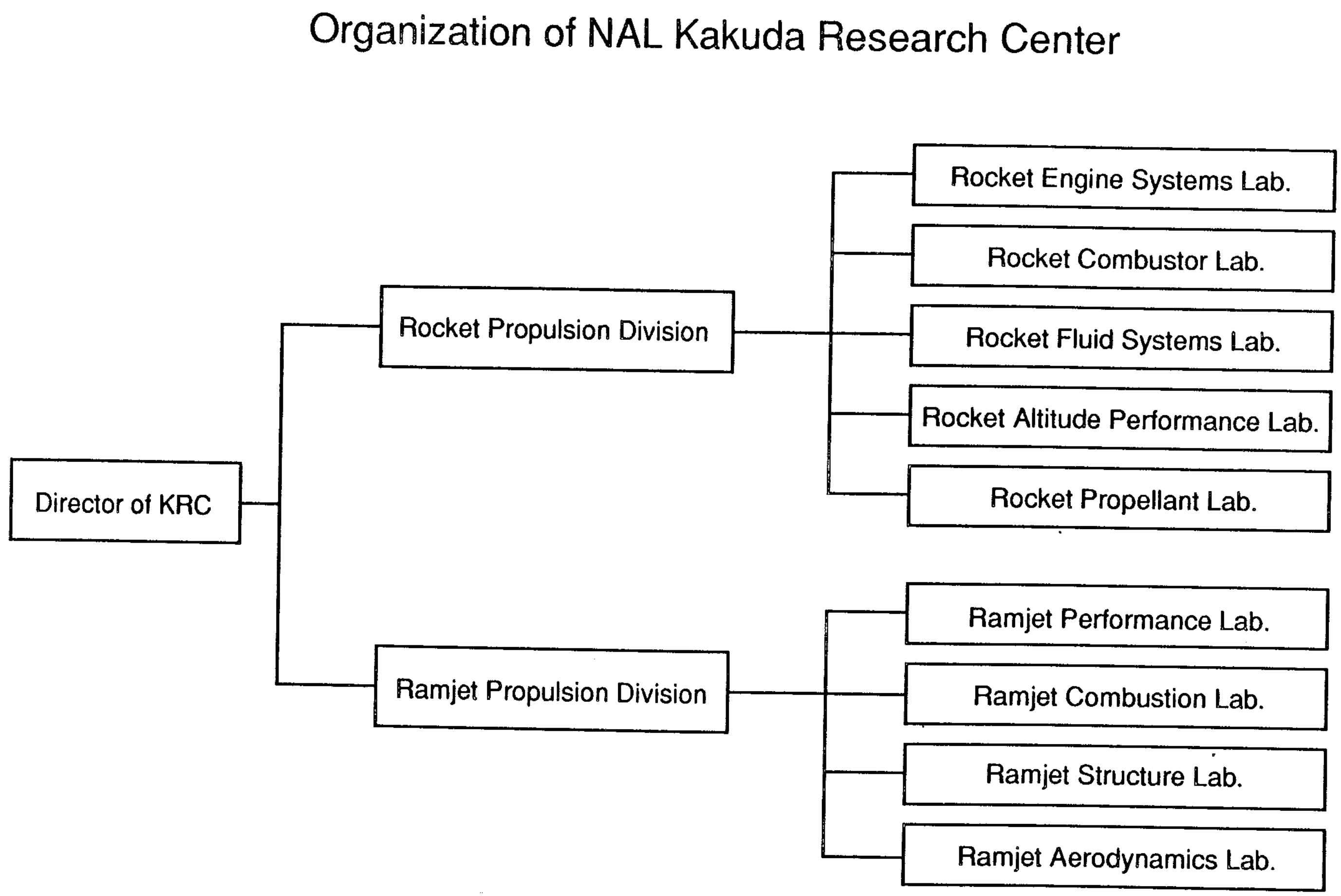


Figure 8. Organization chart for the NAL Kakuda Research Center.

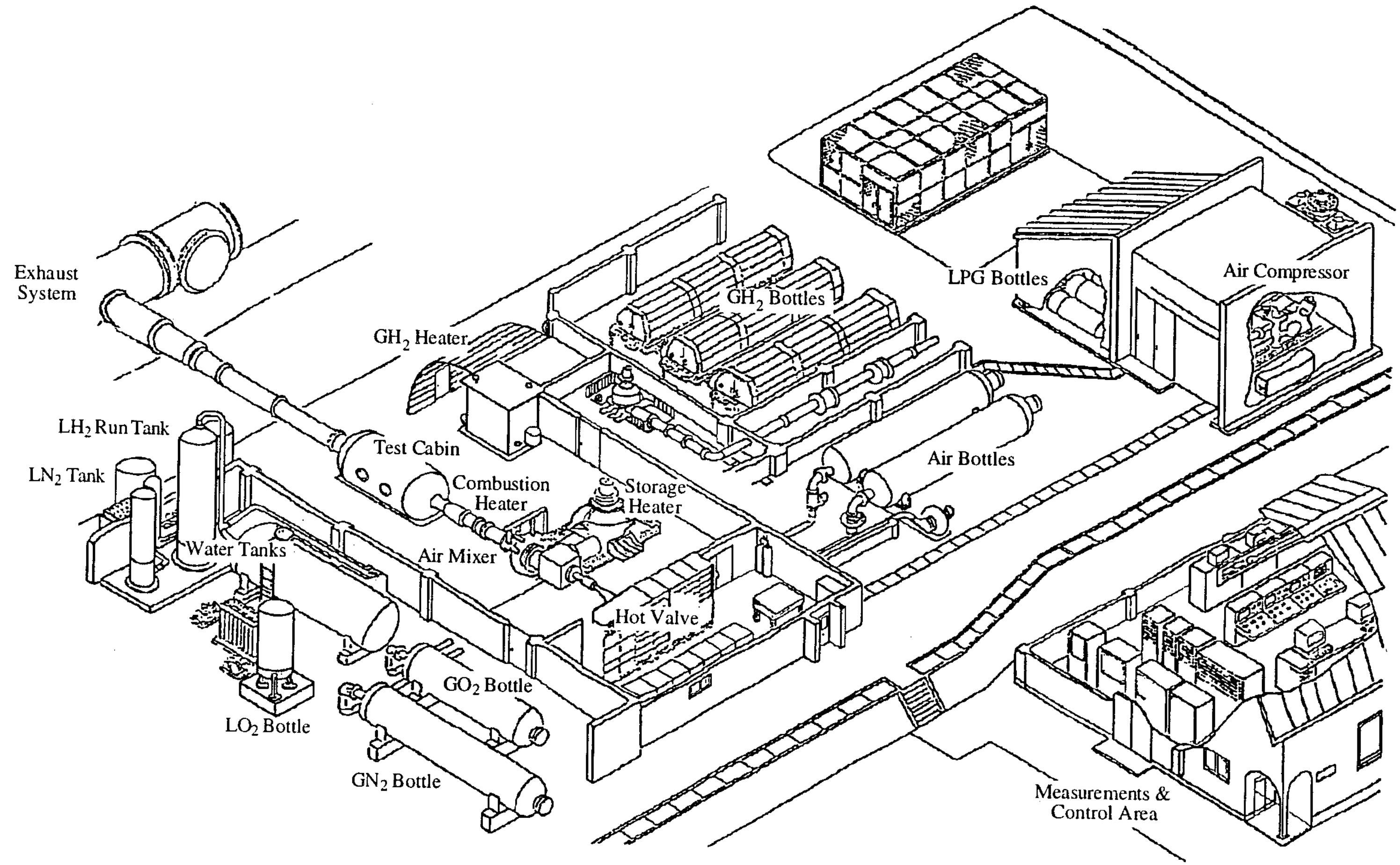


Figure 9. Layout of the ramjet test facility.

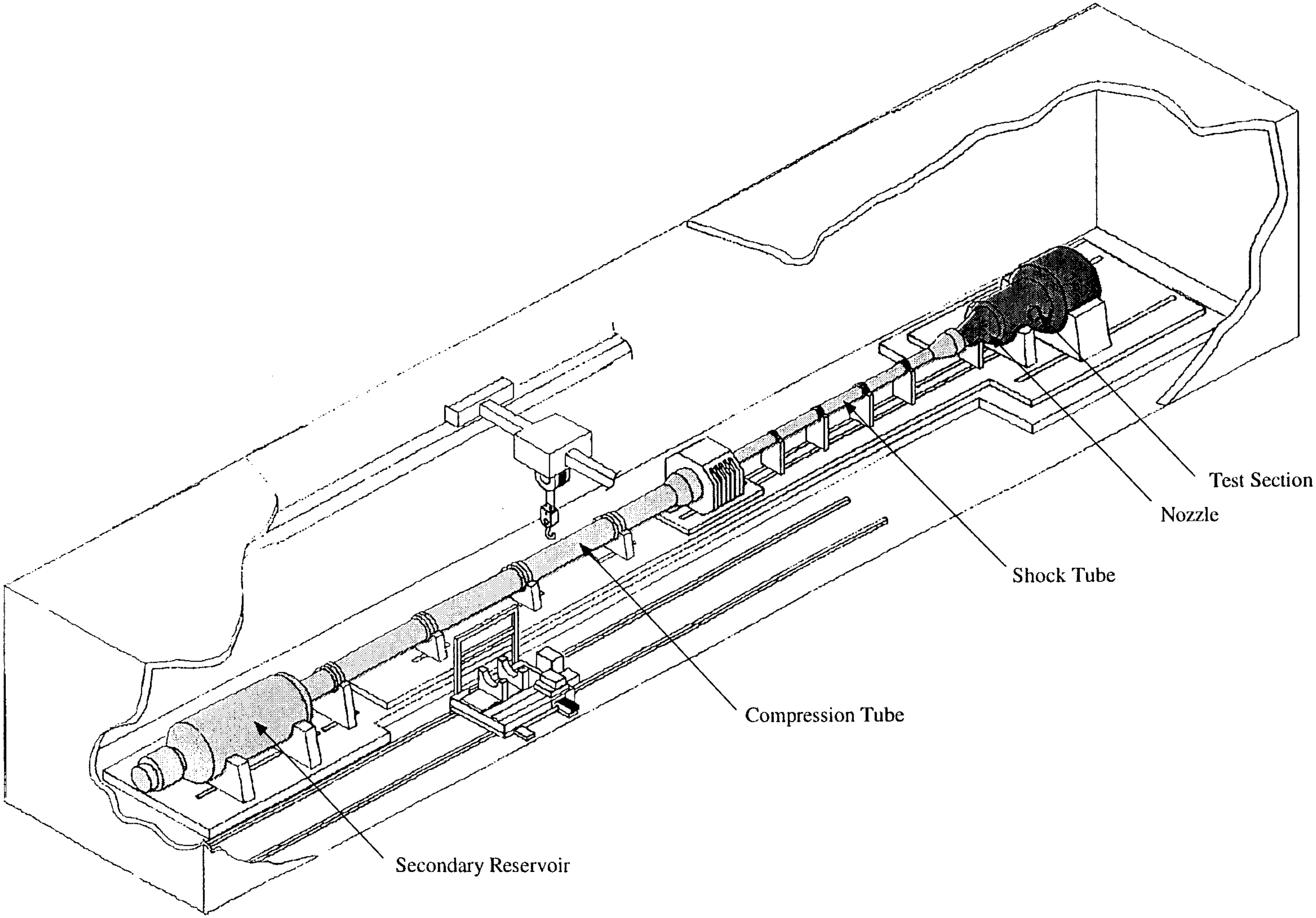


Figure 10. Schematic diagram of the high enthalpy shock tunnel.

System Configuration of Numerical Simulator II

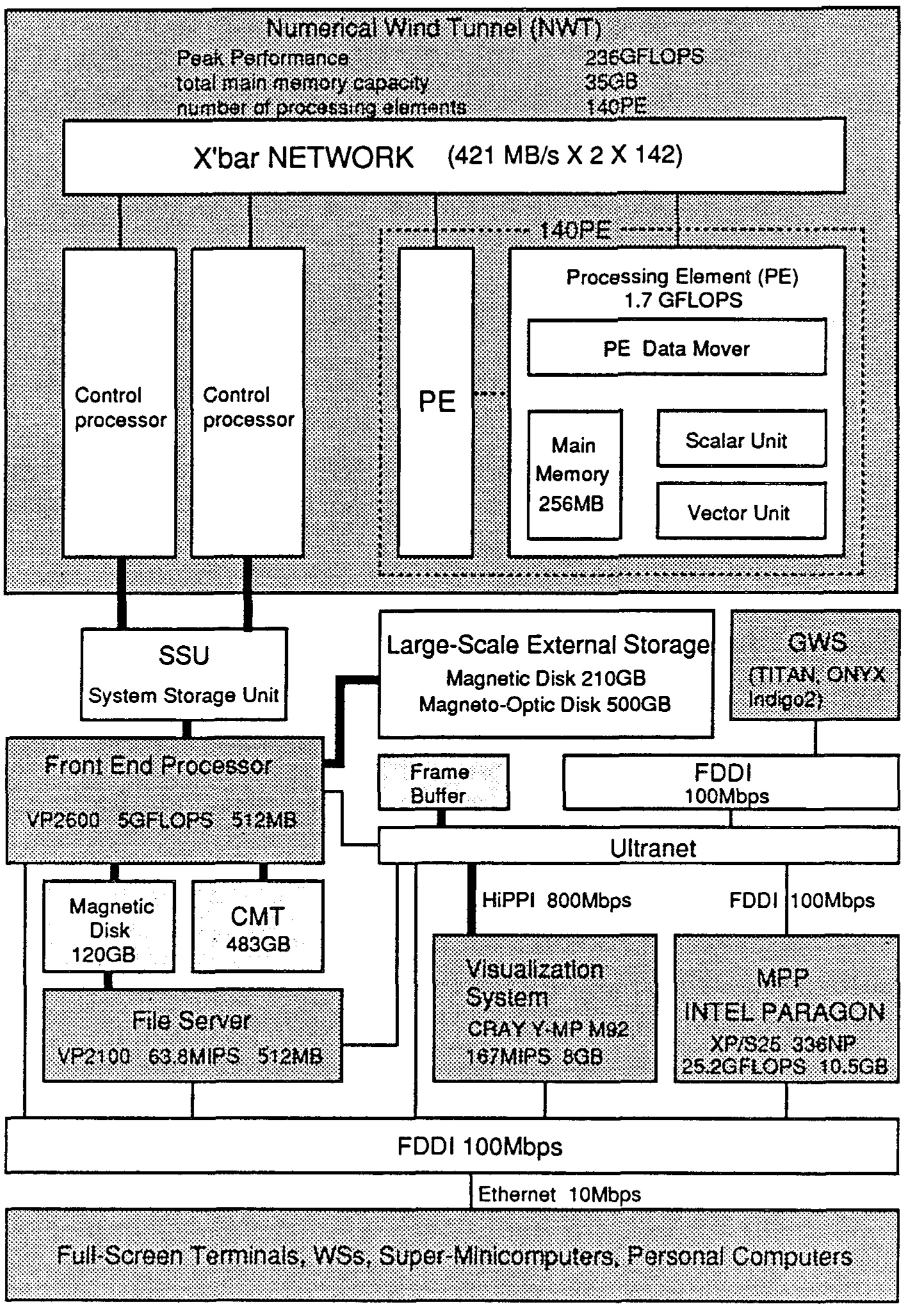


Figure 11. System configuration of the NAL Numerical Simulator II.

Table 1. Japanese Military Contract Amounts for the Top Twenty Comparnies for JFY 1994

Rank	Contractors	No. of Cases	Yen Value 100 M	Percent versus Annual	Major Items
1	MHI	200	2,790	20.6	Ships, Aircraft, Aircraft Repair, Guided Missiles
2	KHI	125	1,482	10.9	Aircraft, Aircraft Repair, Guided Missiles
3	MELCO	214	959	7.1	Electric, Measuring, Comm, Wave, GM
4	NEC	341	531	3.9	Electric, Comm, Wave, GM, Prototype
5	IHI	64	527	3.9	Ships, Aircraft, Aircraft Repair, Prototype
6	ITOCHU	12	474	3.5	Imported Items, Fibers
7	TOSHIBA	169	412	3.0	Electric, Comm, Wave, Supplies, Prototype
8	HITACHI SHIP BUILDING	40	334	2.5	Ships, Machinery, Munitions
9	SUMITOMO HVY IND	27	331	2.4	Ships, Machinery, Weapons
10	NISSAN AUTO	64	296	2.2	Vehicles, Munitions, Prototype
11	FUJI HVY IND	37	248	1.8	Aircraft, Aircraft Repair, Prototype
12	KOMATSO	53	238	1.8	Munitions, Vehicles, Prototype
13	JAPAN COMPUTER	181	212	1.6	Lease of Computer
14	JAPAN STEEL	20	194	1.4	Weapons, GM, Prototype
15	HITACHI	62	158	1.2	Comm, Wave, Machinary, Vehicles
15	DAIKIN IND	67	156	1.2	Munitions, Machinary, Aircaft, Prototype
17	OKI ELEC IND	76	150	1.1	Measuring, Comm, Wave
18	FUJITSU	146	147	1.1	Electric, Measuring, Comm, Wave, Supplies
19	COSMO PETROLEUM	364	96	0.7	Fuel
20	NIPPON PETROLEUM	272	85	0.6	Fuel
Total:		2,543	2,543	72.5	